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ORIGINAL RESEARCH

THE RELIABILITY OF A NOVEL HEEL-RISE TEST VERSUS GONIOMETRY TO ASSESS PLANTARFLEXION RANGE OF MOTION

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ABSTRACT

Background: Ankle plantarflexion (PF) active range of motion (ROM) is traditionally assessed in a non-weight-bearing (NWB) position with a universal goniometer. However, a convenient, reliable, low-cost means of assessing functional PF active ROM in a weight-bearing (WB) position has yet to be established.

Purpose: To compare the intra- and interrater reliability of PF active ROM measurements obtained from a goniometric NWB assessment, and a functional heel-rise test (FHRT) performed in WB.

Study Design: Reliability study.

Methods: Two physical therapy student examiners, blinded to each other's measurements, assessed PF active ROM through a NWB goniometric technique and a FHRT on all subjects within the same test session. Intra- and interrater reliability values were calculated using an intraclass correlation coefficient ($ICC_{2,1}$, $ICC_{2,k}$) and 95% confidence intervals. Standard error of measurement (SEM) and minimal detectable change (MDC) were recorded for each method.

Results: 43 healthy participants (mean $\pm$ SD, age: 22.7 $\pm$ 1.7 years, height: 1.7 $\pm$ 0.1 m, mass: 77.8 $\pm$ 17.2 kg) completed testing procedures. The within-session intrarater reliability ($ICC_{2,1}$) estimates were observed for goniometry (right: 0.96, left: 0.95 - 0.97) and FHRT (right: 0.99, left: 0.99), as well as the interrater reliability ($ICC_{2,k}$) of goniometry (right: 0.79, left: 0.79) and FHRT (right: 0.79, left: 0.87). Goniometry SEM (3.3 - 3.6°) and MDC (9.2 - 9.8°) were observed, in addition to FHRT SEM (0.6 cm) and MDC (1.6 - 1.7 cm). A weak correlation was found between FHRT and goniometric measurements (r = -0.03 - 0.13).

Conclusions: The FHRT was found to have good to excellent intra- and interrater reliability, similar to goniometric measurement. The lack of agreement between these measurements requires further exploration of a WB assessment of ankle PF active ROM.

Level of Evidence: 2b

Key words: Ankle, functional, heel-rise, plantarflexion, range of motion

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INTRODUCTION

The ankle plantarflexors are a muscle group of the lower leg with the primary function of plantarflexion of the ankle joint. Additionally, the plantarflexors have an instrumental role in allowing the knee extensors to stabilize the knee when subjected to ground reaction forces.[1] Ankle range of motion (ROM) is measured and monitored throughout the rehabilitation process to assess joint dysfunction and determine treatment effectiveness,[2] in which ROM is typically assessed both passively and actively. Active ROM is defined as "movement of a segment within the unrestricted ROM that is produced by active contraction of the muscles crossing that joint."[3]

Abnormal ankle plantarflexion (PF) ROM can both contribute to, and result from, various foot and ankle pathologies. Posterior ankle impingement occurs in athletic populations due to forceful PF requirements during athletic activity (i.e. ballet dancers), where a hyperplantarflexion motion places extreme pressure on the structures between the calcaneus and the distal tibia.[4] Excessive PF ROM has also been identified as an injury risk factor for development of medial tibial stress syndrome in military personnel[5] and collegiate athletes.[6] Distally, the typical mechanism for a turf toe injury involves hyperdorsiflexion of the first metatarsal phalangeal joint in combination with hyperplantarflexion of the ankle.[7]

A number of lower extremity conditions are influenced by PF performance in weight-bearing (WB). Following an Achilles tendon repair, excessive tendon lengthening can occur due to separation of the tendon ends from early WB and aggressive rehabilitation.[8] This lengthening can lead to an insufficiency of the tendon and decreased strength in end-range PF.[9] Common ankle sprain sequelae, such as swelling and pain, do not fully explain PF mobility deficits. Miyamoto and colleagues evaluated a cohort of patients with a history of multiple inversion ankle sprains who were experiencing residual pain and restricted PF ROM.[10] Arthroscopy revealed an anterior fibrous bundle running from the distal anterior tibia to the anterior edge of the dome of the talus, which became taut with PF in all cases; however, the study did not specify whether PF ROM measurements were recorded in a WB or non-weight bearing (NWB) position, making it difficult to assume whether the clinical presentation of PF ROM restrictions would be consistent across multiple testing positions. In such instances where PF ROM is deemed less than optimal, appropriate and reliable means of assessment are necessary.

Various methods have been used to evaluate ankle ROM, specifically at the talocrural joint. Measurement of ankle ROM in NWB with a universal goniometer is a common method of evaluating ankle mobility and provides feedback to the clinician in regards to rehabilitation progression and outcome.[11] Despite the routine use of goniometry in physical therapist practice, its reliability has been questioned. Goniometric assessment of PF active ROM has demonstrated good intrarater (ICC = 0.64 – 0.98), but poor interrater reliability (ICC = 0.25), and has proven to be less precise when compared to ankle dorsiflexion (DF) active ROM.[2] The variability in goniometric measurement reliability can be partly attributed to the goniometer's physical construct, starting position, individual anatomy, and body region.[11] Difficulties in finding the joint axis of rotation, as well as properly placing the distal arm of the goniometer along the forefoot, may influence measurement accuracy. [12] These limitations may lead to varying measurement values for the same joint, contributing to error in the final ROM assessment. An incorrect reading may have physical, financial, social, and psychological ramifications for the patient.[11]

Inclinometry is another method used to measure ankle ROM. When using an inclinometer, the device is set to zero degrees at the neutral position of the ankle and the degree of movement in the directions of both ankle DF and PF is assessed. Inclinometry has demonstrated good-excellent interrater reliability when measuring ankle PF in NWB positions with the knee flexed (ICC = 0.86) and extended (ICC = 0.72).[13] Interestingly, it was also noted that intrarater reliability for PF ROM assessment was greater in clinicians with less experience. It was proposed that measuring ankle PF ROM is less common compared to DF; thus, less experienced clinicians may grasp the technique more quickly.

WB assessment of ankle ROM has been explored more recently, specifically for ankle DF. A WB lunge test for ankle DF ROM has been thought to be a more functional test when compared to a NWB approach.[14,15] The torque placed on the dorsiflexed ankle when in a lunge position is much greater than the NWB assessment, which is posited to be representative of daily function. The WB lunge test for ankle DF demonstrated excellent within-session intrarater reliability when assessed via tape measure (ICC = 0.98 – 0.99), digital inclinometer (ICC = 0.96 – 0.97), and goniometer (ICC = 0.85 – 0.96).[15] The WB lunge test also demonstrated excellent interrater reliability when assessed through tape measure (ICC = 0.98) and inclinometry (ICC = 0.97) for raters of varying skill levels.[14] However, a similar WB technique to assess ankle PF ROM has yet to be established.

Various methods of WB assessment of PF performance have traditionally focused on manual muscle testing and endurance,[16] rather than reporting the resultant maximal vertical excursion. In reality, WB heel-rise performance requires adequate active ROM at the talocrural joint and sufficient strength of the gastroc-soleus complex to complete the motion, where muscle strength can be defined as "the ability of contractile tissue to produce tension and a resultant force based on the demands placed on the muscle."[17] Silbernagel and colleagues[18] described a method used to assess PF endurance in those with Achilles tendon rupture through a device that included a spring-loaded string attached to the heel of a shoe. Individuals then completed a single leg heel-rise, and feedback regarding the distance achieved was provided through a digital sensor output. In those with a history of drug use, a more simple method of PF endurance assessment was conducted by performing a heel-rise relative to a five cm block of wood placed on the floor.[19] Additional methods of assessing PF endurance included a laser-guided line positioned above the individual's head placed at 50% of the heel-rise maximum vertical height,[20] while another utilized an electrogoniometer to measure the angle of PF.[21] A recent study investigating PF strength and endurance in aging adults employed a "calf-raise senior" test, which used a horizontal bar above the participant's head to mark the maximum vertical height achieved when performing repetitions of a heel-rise, which demonstrated good intrarater (ICC = 0.79 – 0.84) and excellent interrater (ICC = 0.93-0.96) reliability.[22]

Although the previously mentioned tests may be useful for examining PF strength and endurance as assessed during a traditional heel-rise test, various challenges are inherently present including efficiency, equipment required, and positioning/body mechanics of the examiner to visualize the measurement. Many of the previously mentioned methods did not report the maximal vertical excursion achieved or active ROM, as this was not the primary objective.

The proposed benefits of a WB assessment and the lack of an efficient, reliable, and inexpensive means to assess PF active ROM leaves clinicians with few options to assess this attribute. The purpose of this study was to explore the intra- and interrater reliability of a novel, functional heel-rise test (FHRT) performed in WB to examine active ROM when compared to a NWB technique with a universal goniometer. The authors hypothesized the FHRT would have greater interrater reliability than goniometry, while both tests would demonstrate similar intrarater reliability when measuring PF active ROM.

METHODS

Research Design

The study protocol was approved by the University of South Dakota Institutional Review Board. All subjects signed an approved informed consent form prior to participation. This was a reliability study design.

Subjects

Subjects were recruited from a sample of convenience. Subjects were included if they were between the ages of 18-35 and English-speaking, and were excluded if they reported any previous injury or surgery to the back or lower extremities within the prior six months, reported any balance problems, or were pregnant.

Procedures

The procedures utilized in this study were adapted from Konor and colleagues and summarized in Figure 1.[15] Two second-year physical therapy doctoral students (novice raters) performed the measurements and underwent standardized training with an experienced physical therapist prior to data

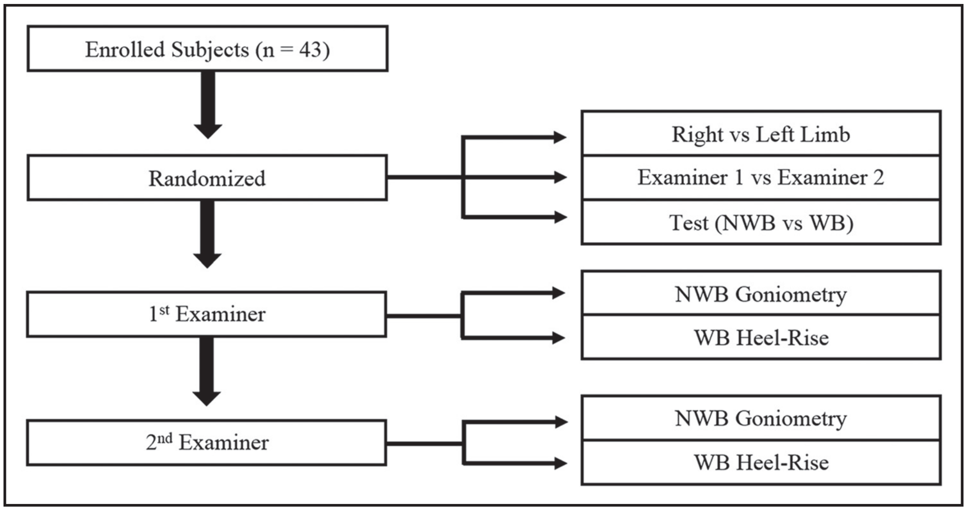

Figure 1. *Procedures, and flow of study.*

collection. With all participants barefoot, only PF active ROM was measured.

Prior to testing, participant's height and body mass were gathered by one examiner. Ankle PF active ROM measurements were recorded by two other researchers during a single session. Examiners were blinded to each other's test results. Testing order for examiner, limb, and active ROM assessment method were randomized with a computer algorithm for each subject. PF active ROM was measured with both the WB unilateral heel-rise and the NWB goniometric technique. Three separate active ROM measurements for each technique were obtained on both the right and left limbs and averaged for data analysis, respectively.

Functional Heel-Rise Test (Weight-bearing)

PF active ROM was assessed in WB using the FHRT (Figure 2). One standard measuring tape labeled in 0.5 cm increments was fixed vertically along a wall, while a second measuring tape was fixed to the floor, starting at the wall-floor interface. The heel-rise was performed on each limb with the participant in a standing position. The stance limb was positioned in relative extension and participants stood facing the wall with the tip of their great toe 15 cm from the wall. Balance was maintained by allowing the participant's fingertips to touch the wall with elbows in 90 degrees of flexion. Participants were instructed to shift their weight onto the test limb and stand as erect as possible, which was monitored by the examiner. The non-stance limb was held in slight knee flexion to attain a NWB position. The examiner stood on a 12.5 inch elevated platform adjacent to the participant to record test results. A steel, 8-inch by 12-inch IRWIN carpenter square tool (Stanley Black & Decker, Inc., New Britain, CT, USA) was aligned vertically on the wall and rested atop the midline of the participant's head to measure starting position (Figure 3). Participants were instructed to perform a maximal unilateral heel-rise by rising onto their toes, with the angle device maintained in position throughout the motion by the examiner. The participant was instructed to perform a simple up and down motion at a self-selected speed, without any prolonged hold. The participant's maximum height was recorded at the completion of the movement. FHRT score was calculated by subtracting the starting height from the participant's maximum height. Three FHRT measurements were recorded on each limb and averaged, respectively. Each participant underwent three practice trials followed by a 30-second rest period prior to three test trials on each limb. Test trials were recorded by the first examiner, and then the second examiner entered the room and the tests were repeated upon exit of the first examiner. Alternating blinded examiners was performed for both NWB and FHRT assessments.

Gonioimetry Measurement (Non-Weight-bearing)

PF active ROM was assessed in NWB using a universal goniometer with the participant supine with

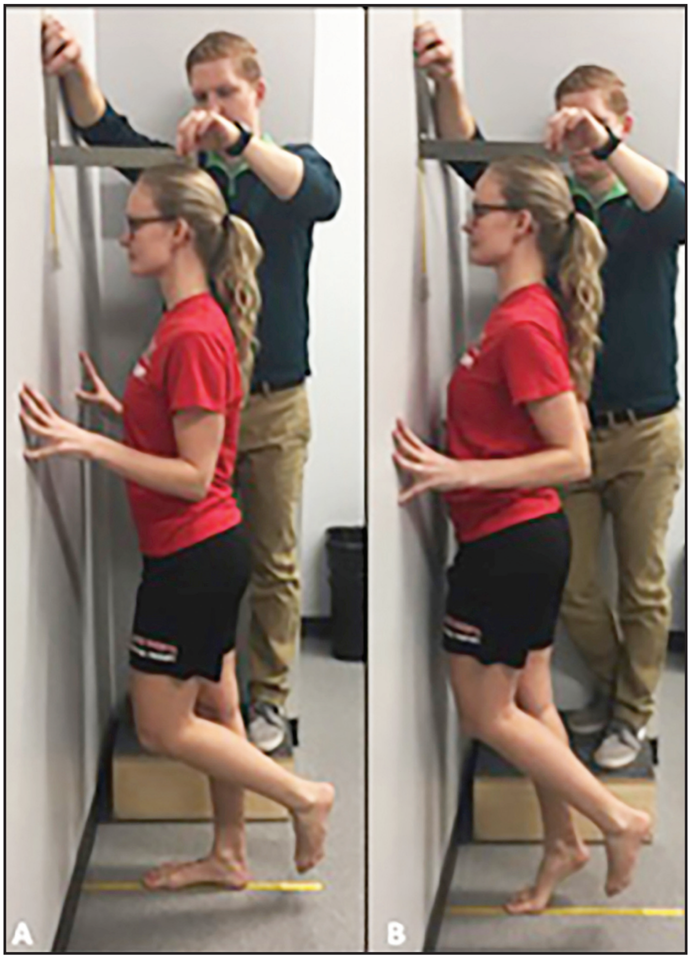

Figure 2. *Functional Heel-Rise Test of Plantarflexion Active Range of Motion (Weight-bearing).*

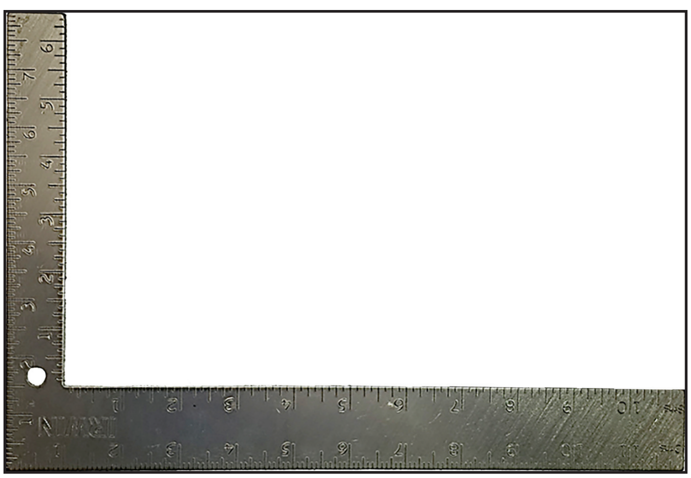

Figure 3. *Carpenter Square Tool.*

their feet off the edge of the treatment table (Figure 4), as previously described.[13] The measurements were taken with knees extended to maintain consistency with the position of the knee during the FHRT.

Figure 4. *Goniometer Assessment of Plantarflexion Active Range of Motion (Non Weight-bearing).*

Initially, the examiner placed the participant's foot in a position of neutral DF. The axis of the goniometer was aligned just distal to the lateral malleolus with the arms aligned with the fibula and fifth metatarsal.[12] The participants were instructed to maximally perform a PF motion. Three measurements were documented and averaged for each participant on each limb and recorded in degrees.

Statistical Methods

Analyses were conducted using R statistical software[23] and included descriptive statistics, reliability coefficients, and Pearson correlations. Additionally, a paired t-test procedure was applied to compare the mean differences between goniometer and heel-rise variables. An alpha value was set at 0.05. Intraclass correlation coefficient (ICC) with a 95% confidence interval was used to determine intra- and interrater reliability, where the following criteria were applied: < 0.5 (poor), 0.5 – 0.75 (moderate), 0.75 – 0.9 (good), and > 0.9 (excellent).[24] The standard error of measurement (SEM) and the minimal detectable change (MDC) values were calculated. The standard error of measurement (SEM) determines the error present in the examiner's recorded measurements when attempting to estimate the true measurements; $SEM = SD \sqrt{1\text{-}ICC}$ (SD = standard deviation).[25] The 95% confidence interval value was used to calculate the MDC, which is the smallest amount of change that can be attributed to a true change rather than an error in the measurement, in which $MDC = SEM * 1.96 * \sqrt{2}$.[25]

Table 1. *Plantarflexion Active Range of Motion: Interrater Reliability ($ICC_{2,k}$), Standard Error of Measurement (SEM), and Minimal Detectable Change (MDC).*

	Right			Left		
	$ICC_{2,k}$ (95% CI)	SEM	MDC	$ICC_{2,k}$ (95% CI)	SEM	MDC
Goniometer	0.79 (0.46, 0.91)	3.3°	9.2°	0.79 (0.55, 0.89)	3.6°	9.8°
Heel-Rise	0.79 (0.61, 0.88)	0.6 cm	1.7 cm	0.87 (0.76, 0.93)	0.6 cm	1.6 cm

Table 2. *Plantarflexion Active Range of Motion: Intrarater Reliability ($ICC_{2,1}$), Standard Error of Measurement (SEM), and Minimal Detectable Change (MDC).*

		Right			Left		
		$ICC_{2,1}$ (95% CI)	SEM	MDC	$ICC_{2,1}$ (95% CI)	SEM	MDC
Examiner 1	**Goniometer**	0.96 (0.90, 0.98)	1.7°	4.7°	0.97 (0.94, 0.98)	1.6°	4.3°
	Heel-Rise	0.99 (0.97, 0.99)	0.2 cm	0.4 cm	0.99 (0.99, 0.99)	0.2 cm	0.5 cm
Examiner 2	**Goniometer**	0.96 (0.94, 0.98)	1.4°	4.0°	0.95 (0.91, 0.97)	1.8°	4.9°
	Heel-Rise	0.99 (0.98, 0.99)	0.1 cm	0.4 cm	0.99 (0.99, 0.99)	0.2 cm	0.4 cm

Table 3. *Paired T-Test Comparing Examiner Measurements of Goniometry and Heel-Rise.*

Paired t-test				
		Examiner 1	Examiner 2	*p* value
Goniometer	Right	66.6 ± 8.39	62.97 ± 7.17	< 0.001*
	Left	66.12 ± 8.97	62.95 ± 7.82	<0.01*
Heel-Rise	Right	8.86 ± 1.52	9.08 ± 1.36	0.24
	Left	8.64 ± 1.79	8.82 ± 1.58	0.30

Values expressed as mean ± standard deviation; *Statistically significant difference at $p \leq 0.05$

Results

Forty-three healthy volunteers (23 females, 20 males) completed testing procedures (mean $\pm$ SD, age: 22.7 $\pm$ 1.7 years, height: 1.7 $\pm$ 0.1 m, mass: 77.8 $\pm$ 17.2 kg). Goniometric and FHRT interrater reliability coefficients ($ICC_{2,k}$), along with SEM and MDC values are described in Table 1 for the right and left limbs, respectively. Both measurement techniques demonstrated good to excellent interrater reliability (ICC = 0.79 – 0.87) across both limbs. Intrarater reliability ($ICC_{2,1}$), SEM, and MDC values for goniometry and the FHRT are summarized in Table 2, with excellent reliability reported for goniometry (ICC = 0.95 -0.97), as well as the FHRT (ICC = 0.99).

Descriptive data were calculated for each examiner according to measurement method. Paired t-test results are summarized in Table 3, which revealed significant differences between goniometric measurements among examiners on both limbs. A weak correlation (r = -0.03 - 0.13) existed between the goniometric and FHRT measurements.

Discussion

The FHRT demonstrated good to excellent intra- and interrater reliability. Previous investigations have noted that raters of varying levels of experience can reliably measure NWB[13] and WB[14] ankle ROM, which is further supported by the findings of the current study. Also, significant differences were found between examiners when measuring ankle PF active ROM with goniometry, but this trend was not observed for the FHRT. Contrary to some of the challenges previously mentioned with goniometry, as well as the conflicting evidence around the reliability of surface palpation in other body regions,[26-28] the FHRT does not require palpating bony landmarks nor aligning equipment with said landmarks, which may increase the ease of its use. This highlights the potential utility of the FHRT, which may lead to increased clinician confidence when WB measurements are recorded between multiple rehabilitation specialists, including those with minimal experience. This notion is especially important, given the relevance of a team-based approach to interdisciplinary patient care in contemporary clinical practice. Future research may wish to investigate the FHRT among clinicians of various healthcare disciplines and levels of experience.

The FHRT, as measured by vertical excursion distance, attempts to capture a more functional measure of PF active ROM compared to traditional NWB goniometry. Several components of motor control are required to execute a standing heel-rise including motor planning, unilateral weight support, balance, and coordination,[16,20] in addition to adequate mobility and muscle power of the foot and ankle complex. The authors posit the FHRT is a functional measure of PF active ROM requiring multiple links in the kinematic chain to work effectively (balance, motor control, mobility, etc.). This notion has been investigated in other single limb tasks, such as evaluating the influence of hip strength on frontal plane knee motion with a single leg squat,[29] or the contributions of ankle DF ROM when performing a lateral step-down test.[30] Additionally, the Star Excursion Balance Test's evaluation of single limb dynamic balance requires varying degrees of hip strength[31] and ankle DF ROM.[32] In terms of WB assessment of ankle mobility, the WB lunge test for ankle DF ROM does not require the same degree of muscle power and balance in comparison to the FHRT – making the FHRT perhaps a more complex test with additional opportunities for movement variability. Future research should investigate the different contributions to FHRT performance along the kinematic chain.

The lack of correlation between goniometric and FHRT measurements may suggest these measure different constructs of ankle mobility. While goniometry may assess PF active ROM at the talocrural joint with contributions from the midfoot/forefoot, performance of the FHRT may also require adequate mobility of the great toe in order to complete the test. Locally at the ankle-foot region, adequate ankle and foot mobility, muscle power from the gastroc-soleus complex, and a degree of dynamic stability are required to successfully maintain single limb stance in order to perform a heel-rise. The authors posit the discrepancy observed between NWB and WB active ROM may partly be due to individual differences in the use of available muscle power – highlighting the need for both a NWB and WB assessment of ankle PF active ROM, as measuring ankle mobility in only one position may lead to improper assumptions by the clinician and adversely affect patient outcomes.

It has been accepted that assessment of heel-rise performance can be evaluated at the foot and ankle region,[18,19,21] or at the head by the amount of vertical excursion as determined by change in height.[20,22] Measurements taken at the two body regions both have benefits and drawbacks. When evaluating a heel-rise through a measurement at the foot and ankle, the measurement is perhaps more accurate in terms of motion that is occurring locally at the heel relative to the ground. However, measurement through various techniques at the foot and ankle region can be challenging for the rehabilitation specialist, as it may require adequate visualization and palpation of bony landmarks in order to properly align equipment. Measurement of WB heel-rise performance at the head, as with the FHRT, offers the potential advantage of improved visualization and examiner/patient interaction, allowing for more meaningful patient feedback. The authors feel this method is also easier, and perhaps more efficient, for novice clinicians to perform, as palpation of body landmarks is not required. However, as previously mentioned, there is perhaps greater movement variability when performing the FHRT, which one may argue that ankle ROM is only one component assessed.

Although the current investigation included only healthy participants without a history of recent foot/ankle pathology or balance issues, the importance of heel-rise performance in clinical populations may justify further exploration of the FHRT. Deficits in heel-rise height were identified in patients who sustained an Achilles tendon rupture and experienced subsequent tendon elongation at 6 and 12 months post-injury.[8] The measurement technique used a spring-loaded string attached to the heel of a shoe, where unilateral heel-rise height mean values for the uninjured (healthy) side were attained (12.9 – 14.7 cm), which were somewhat higher than FHRT mean values (8.6 – 9.1 cm). If exploring heel-rise performance in clinical populations, differences in testing methods should be taken into account when comparing outcomes.

Limitations

Blinding of the participants and researchers to the testing procedure and limb was not possible due to the nature of the data collection process. Also, examiners were not blinded to their own goniometer and FHRT measurements, which may have introduced a degree of examiner bias. In addition, generalizability of study outcomes is limited due to a sample of convenience including healthy, adult participants.

CONCLUSION

The FHRT demonstrated good to excellent intra- and interrater reliability among novice examiners, similar to goniometric measurement. The lack of agreement between these measurements requires further exploration of a WB assessment for ankle PF active ROM.

REFERENCES

1. McGrath M, Howard D, Baker R. A forward dynamic modelling investigation of cause-and-effect relationships in single support phase of human walking. *Comp Math Methods Med.* 2015;2015:383705.
2. Youdas JW, Bogard CL, Suman VJ. Reliability of goniometric measurements and visual estimates of ankle joint active range of motion obtained in a clinical setting. *Arch Phys Med Rehabil.* 1993;74(10):1113-1118.
3. Kisner C, Colby LA. Range of motion. In: Kisner C, Colby LA, eds. *Therapeutic Exercise: Foundations and Techniques*. 6th ed. Philadelphia, PA: F.A. Davis; 2012:52.
4. Hayashi D, Roemer FW, D'Hooghe P, Guermazi A. Posterior ankle impingement in athletes: pathogenesis, imaging features and differential diagnoses. *Eur J Radiol.* 2015;84(11):2231-2241.
5. Moen MH, Bongers T, Bakker EW, et al. Risk factors and prognostic indicators for medial tibial stress syndrome. *Scand J Med Sci Sports.* 2012;22(1):34-39.
6. Hubbard TJ, Carpenter EM, Cordova ML. Contributing factors to medial tibial stress syndrome: a prospective investigation. *Med Sci Sports Exerc.* 2009;41(3):490-496.
7. Childs SG. The pathogenesis and biomechanics of turf toe. *Orthop Nurs.* 2006;25(4):276-280.
8. Silbernagel KG, Steele R, Manal K. Deficits in heel-rise height and Achilles tendon elongation occur in patients recovering from an Achilles tendon rupture. *Am J Sports Med.* 2012;40(7):1564-1571.
9. Mullaney MJ, McHugh MP, Tyler TF, et al. Weakness in end-range plantar flexion after Achilles tendon repair. *Am J Sports Med.* 2006;34(7):1120-1125.
10. Miyamoto W, Takao M, Matsushita T. Anterior fibrous bundle: a cause of residual pain and restrictive plantar flexion following ankle sprain. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(6):1385-1389.
11. Clapper MP, Wolf SL. Comparison of the reliability of the Orthoranger and the standard goniometer for assessing active lower extremity range of motion. *Phys Ther.* 1988;68(2):214-218.
12. Russell JA, Shave RM, Kruse DW, et al. Is goniometry suitable for measuring ankle range of motion in female ballet dancers? An initial comparison with radiographic measurement. *Foot Ank Special.* 2011;4(3):151-156.
13. Dobija LW, Jankowski KS. Reliability of the nonweightbearing inclinometric measurements of the ankle range of motion in older adults with orthopedic problems. *Top Geriatr Rehabil.* 2015;31(2):164-169.
14. Bennell KL, Talbot RC, Wajswelner H, et al. Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. *Aust J Physio.* 1998;44(3):175-180.
15. Konor MM, Morton S, Eckerson JM, et al. Reliability of three measures of ankle dorsiflexion range of motion. *Int J Sports Phys Ther.* 2012;7(3):279-287.
16. Lunsford BR, Perry J. The standing heel-rise test for ankle plantar flexion: criterion for normal. *Phys Ther.* 1995;75(8):694-698.
17. Kisner C, Colby LA. Resistance exercise for impaired muscle performance. In: Kisner C, Colby LA, eds. *Therapeutic Exercise: Foundations and Techniques*. 6th ed. Philadelphia, PA: F.A. Davis; 2012:158.
18. Silbernagel KG, Nilsson-Helander K, Thomee R, et al. A new measurement of heel-rise endurance with the ability to detect functional deficits in patients with Achilles tendon rupture. *Knee Surg Sports Traumatol Arthrosc.* 2010;18(2):258-264.
19. Pieper B, Templin TN, Birk TJ, et al. The standing heel-rise test: relation to chronic venous disorders and balance, gait, and walk time in injection drug users. *Ostomy Wound Manage.* 2008;54(9):18-32.
20. Yocum A, McCoy SW, Bjornson KF, et al. Reliability and validity of the standing heel-rise test. *Phys Occup Ther Pediatr.* 2010;30(3):190-204.
21. Jan MH, Chai HM, Lin YF, et al. Effects of age and sex on the results of an ankle plantar-flexor manual muscle test. *Phys Ther.* 2005;85(10):1078-1084.
22. Andre HI, Carnide F, Borja E, et al. Calf-raise senior: a new test for assessment of plantar flexor muscle strength in older adults: protocol, validity, and reliability. *Clin Interv Aging.* 2016;11:1661-1674.
23. R Core Team. R: A language and environment for statistical computing. The R Foundation for Statistical Computing Web site. https://www.R-project.org/. 2015. Accessed July 18, 2017.
24. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med.* 2016;15(2):155-163.
25. Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice.* 3rd ed. Upper Saddle River, NJ: Pearson Prentice Hall; 2009.

26. Cooperstein R, Hickey M. The reliability of palpating the posterior superior iliac spine: a systematic review. *J Can Chiropr Assoc.* 2016;60(1):36-46.

27. Decary S, Ouellet P, Vendittoli PA, et al. Reliability of physical examination tests for the diagnosis of knee disorders: evidence from a systematic review. *Man Ther.* 2016;26:172-182.

28. Haneline MT, Young M. A review of intraexaminer and interexaminer reliability of static spinal palpation: a literature synthesis. *J Manipulative Physiol Ther.* 2009;32(5):379-386.

29. Claiborne TL, Armstrong CW, Gandhi V, et al. Relationship between hip and knee strength and knee valgus during a single leg squat. *J Appl Biomech.* 2006;22(1):41-50.

30. Rabin A, Kozol Z. Measures of range of motion and strength among healthy women with differing quality of lower extremity movement during the lateral step-down test. *J Orthop Sports Phys Ther.* 2010;40(12):792-800.

31. Ness BM, Comstock BA, Schweinle WE. Changes in dynamic balance and hip strength after an eight-week conditioning program in NCAA division I female soccer (football) athletes. *Int J Sports Phys Ther.* 2016;11(7):1054-1064.

32. Hoch MC, Staton GS, McKeon PO. Dorsiflexion range of motion significantly influences dynamic balance. *J Sci Med Sport.* 2011;14(1):90-92.